Complementarity between internal knowledge creation and external knowledge sourcing in developing countries

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Complementarity between internal knowledge creation and external knowledge sourcing in developing countries

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Abstract: In developing countries, innovation is to a large extent a matter of adoption of advanced technologies but also of conducting internal R&D to be able to better assimilate existing technologies. This paper, based on firm level data from 24 developing countries, examines the roles of internal R&D efforts (MAKE) and external technology sourcing (BUY) in fostering productivity in manufacturing firms. Is MAKE a substitute for BUY or are the two strategies complementary as evidenced in some developed countries? Our empirical investigation highlights the critical role of external technology acquisition in manufacturing industries in low-income countries and exhibits signs of complementarity only in middle-income countries.

Keywords: innovation, make and buy, complementarity, developing countries

JEL code: O13, O33, D22

1. Introduction

Much of the economic and social progress of the past few centuries has benefited from technological progress. Innovation has been considerably discussed in the endogenous growth theory (Aghion and Howitt, 1998; Grossman and Helpman, 1991), where it is modelled as being driven by an R&D sector. Although the number of studies examining the influence of innovation on productivity is increasing, most of the empirical studies on innovation and productivity have been conducted on developed country data (see Mairesse et al., 2011 for a review). In developing countries, innovation is more a process of learning and assimilation of knowledge in an effort to catch-up with the technological frontier than a process of creation and discovery (Fransman and King, 1984).

The current study will focus on knowledge sourcing strategies in developing countries. Two types of technology sourcing are distinguished. Firms can obtain new technologies by conducting their own R&D (MAKE) or they can acquire new technologies through licensing, hiring new personnel, or investing in new machinery (BUY). We shall address two questions: What are the comparative returns of the two sources of knowledge? And are the two substitutes or complements, i.e. is there a choice between one or the other, or should they be conducted jointly?

The analysis is based on firm level data from 24 low- and middle-income countries[1]. We test the existence of complementarity between MAKE and BUY by estimating demand equations for the two knowledge sourcing strategies, which are derived from a production function that allows for a synergy between them. This way of testing for complementarity, which is borrowed from Miravete and Pernías (2006), allows the separate identification of a synergy between the two strategies and the unexplained correlation between the error terms in the respective demand equations. The result suggests that firms in low-income countries rely more on external sourcing and firms in middle-income countries more on in-house R&D, while a synergy between internal and external knowledge sourcing exists in middle-income countries but not in low-income countries.

This paper proceeds as follows. The next section sets the background by reviewing the feature of innovation strategies in developing countries and existing evidence on complementarity in innovation studies. Section 3 presents the empirical model and

[1] The classification into middle-income and low-income countries is taken from "World Bank country classification 2011". See footnote 12.

methods to test for complementarity. The data and the variables used will be presented in section 4. The results are interpreted in section 5. The last section summarises and concludes.

2. MAKE and BUY in developing countries: complements or substitutes?

2.1 Something more than R&D?

Cooper (1989) explained the differences in characteristics between innovation in industrialized economies and developing countries. As he pointed out it is a rather limited view of innovation theories to be only concerned with the initial introduction of products or processes. Most firms in developing countries attempt to reach the technological frontier instead of achieving inventions that are new to the market.

At a low stage of development, firms normally face obstacles such as inadequate human capital and poor infrastructure. In-house innovative activities are severely constrained for a majority of firms. Freeman (1989) suggested that external knowledge sourcing has a significant influence on the learning process. He argued that for the most part even the most technologically advanced firms in developing countries are committed to be involved in external sourcing activities. Aggarwal (2000) explained that external technology plays two important roles in developing economies: filling gaps in domestic technological capability and upgrading the existing technologies to international standards. By enhancing the technological capability, external technology sourcing benefits in-house R&D.

However, acquiring external knowledge per se does not guarantee that a firm will achieve successful learning (Matusik, 2000). For external knowledge to be exploited effectively, it has to be combined with a complementary knowledge base within the firm. Cooper (1989) mentioned that failure to learn is in fact quite common in developing countries because the firms there that receive technology via external sources are quite often unconcerned about how to develop and appropriate this internal technological capability. Cohen and Levinthal (1989) define “absorptive capacity” to describe the substantial role of a stock of prior knowledge in order to absorb external know-how. They argue that the in-house R&D process would at the same time accommodate firms to build up their own technological capability. This technological capability within firms is needed in order to understand the tacit components of the technology (Desai, 1989; Lall, 1989; Mowery and Oxley, 1995).

The paradigm of open innovation demonstrated that firms should make the best use of internal and external knowledge (Chesbrough, 2003). This perspective not only emphasizes the significant value of external knowledge, it also indicates that firms organize their internal R&D in part in order to absorb the wealth of available external knowledge. Such a mutual interaction implies the possible complementary between own and external sources of knowledge.

2.2 Definition of complementarity

A pair of economic activities is complementary if (1) adopting one activity does not preclude adopting the other and if (2) whenever it is possible to implement each activity separately, the sum of the benefits of doing each separately is not greater than the benefit of doing both together (Milgrom and Robert; 1990). The theorem states that if each pair of activities in a group is complementary, then implementing any subset of the activities in the group raises the incremental return to implementing the remaining ones (Topkis 1978). This notion of complementarity between activities was first introduced in economics by Vives (1990) and then further developed by Milgrom and Roberts (1990, 1995).

More formally, suppose there are two discrete technology acquisition practices, MAKE and BUY. Z is a vector of exogenous variables. The objective function f(MAKE, BUY, Z) is supermodular if the following inequality holds for all values of the other arguments of f:

$$f(1, 1; Z) - f(1, 0; Z) > f(0,1;Z) - f(0, 0; Z) \quad (1)$$

MAKE and BUY are complementary if the presence of one strategy (e.g. MAKE) increases the marginal return of adopting the other strategy (BUY), after controlling for other exogenous effects[2] (Milgrom and Robert, 1990). Conversely, MAKE and BUY are substitutes if the inverse inequality holds for (1).

2.3 Evidence of complementarity in innovation studies

The notion of complementarity is commonly refer to cross-price effects in demand theory. During the past decades, many studies have broadened this concept to analyse more complex economic phenomena, organizational structures and government policies. Here,

[2] If MAKE and BUY are continuous variables, an equivalent inequality restriction would imply that the incremental effect of one practice on the objective function increases with an increase in the other practice. $\frac{\partial^2 f(r_b, r_m, Z)}{\partial r_b \partial r_m} > 0$; where r_b is BUY and r_m is MAKE

we briefly review some key studies in both economic and management literature that have estimated the complementarity versus substitutability in ways of technology sourcing.

In emerging economies, complementarity in innovation mainly focuses on investigating the inter-dependent relation between in-house R&D and imported technology. Braga and Willmore (1991) found that there is a robust complementary relationship between technology buying and firm technology effort in Brazilian industry. Deolalikar and Evenson (1989) showed that technology transferred from abroad and in-house R&D are complementary rather than substitutive avenues of technology acquisition. Kim and Nelson (2000) also argued that the process of learning through the external technology sourcing serves as an effective experience that paves the way for indigenous technological innovation in Indian firms.

Besides, complementarity in innovation has also been shared by lots of studies across developed economies. Arora and Gambardella (1990) test the synergetic effects among four different external sourcing strategies of large American chemical and pharmaceutical firms. The results show that there is complementarity between all types of external sourcing strategies. Veugelers (1997) finds that the external sourcing strategy stimulates internal research activities in Belgian manufacturing firms. It seems that external knowledge sources leverage the innovative power of in-house R&D. This result is also found in a study undertaken by Lokshin, Belderbos and Carree (2008). In a recent study Cassiman and Veugelers (2006) found a strong synergy relationship between firms' internal R&D and disembodied knowledge sourcing strategies in Belgian manufacturing firms.

On the other hand, some studies have found evidence on substitutability between innovation activities. Mytelka (1987) found that external imports of technology discourage Andean group countries to undertake in-house innovation activities. Fikkert (1993) used the Indian manufacturing firm data to regress the technology imports on in-house R&D efforts. Their findings support the hypothesis of negative relationship between technology imports and R&D efforts. Basant and Fikkert (1996) estimated the return of R&D, technology imports and their interaction term in the production function by using Indian firm level panel data. They found that the estimated rate of return of technology imports is much higher than the return to in-house R&D. The results also imply a substitutive relation between R&D efforts and external technology in the production of knowledge. Katrak (1997) also found that the probability of importing technology was only weakly influenced by R&D efforts and the external sourcing had a significant negative effect on the R&D labour intensity in Indian electrical and electronics industries.

Despite the rich literature on technology making and buying in developing countries, the results are far from conclusive. What distinguishes this study from the previous studies is, first of all, the use of a recent methodology for testing complementarity that controls for the correlation between unobservables in the strategy equations, and, secondly, the use of a unique dataset of 24 developing countries that allows to investigate differences in complementarity at different levels of development.

3. Testing for complementarity

In this section we explain the way complementarity in technology acquisition strategies can be identified and tested.

In empirical studies, the most popular approach applied to investigate complementarity between economic activities consists in directly estimating the cross partial derivatives in the production function. This approach is defined as the Production approach (PROD). It aims at testing the complementarily for a specific objective function. It has been applied in several empirical studies (Cassiman and Veugelers, 2006; Mohnen and Röller, 2005; Belderbos et al., 2006).

Suppose that a firm uses two knowledge acquisition strategies, y_{mi}, referring to MAKE or internal knowledge acquisition, and y_{bj}, referring to BUY or external knowledge acquisition. The technology is represented by a standard Cobb-Douglas production function $Q_i = f(K_i, L_i, y_{mi}, y_{bi}, Z_i)$, where K and L represent respectively capital and labour, and Z stands for a group of control variables that capture the firm- and organization-specific characteristics. In logarithmic terms, denoting logarithmically transformed continuous variables by small letters, we have

$$q_i = \alpha k_i + \beta l_i + \theta_{00}(1-y_{bi})(1-y_{mi}) + \theta_{10} y_{bi}(1-y_{mi}) + \theta_{01}(1-y_{bi}) y_{mi} + \theta_{11} y_{bi} y_{mi} + \chi Z_i + e_i \qquad (2)$$

where α and β are the output elasticities of capital and labour, y_{ji} (j=b,m) are binary choice variables taking the value 1 if the corresponding strategies are adopted by firm i, θ_{11}, θ_{01}, θ_{10}, and θ_{00} capture the productivity obtained when respectively MAKE and BUY, only BUY, only MAKE and neither MAKE nor BUY are chosen, and e_{it} is a random error term.

The PROD approach estimates the existence of complementarity directly by regressing the objective function on exclusive combinations of innovation activities. The production function is supermodular in y_{bi} and y_{mi} if

$$\theta_{11} - \theta_{01} - \theta_{10} + \theta_{00} > 0. \tag{3}$$

The inequality expresses the fact that the presence of one innovation activity increases the marginal return of adopting another activity. Conversely, the two activities are substitutive if

$$\theta_{11} - \theta_{01} - \theta_{10} + \theta_{00} < 0. \tag{4}$$

An alternative form can be written in the follow way:

$$q_i = \alpha k_i + \beta l_i + \theta_0 + \theta_b y_{bi} + \theta_m y_{mi} + \theta_{bm} y_{bi} y_{mi} + \chi Z_i + e_i \tag{5}$$

where

$$\begin{aligned} \theta_0 &= \theta_{00} \\ \theta_b &= \theta_{10} - \theta_{00} \\ \theta_m &= \theta_{01} - \theta_{00} \\ \theta_{bm} &= \theta_{11} + \theta_{00} - \theta_{10} - \theta_{01}. \end{aligned} \tag{6}$$

Coefficient θ_m captures the non-exclusive partial effects of MAKE, θ_b the non-exclusive partial effect of BUY, θ_{bm} the returns of adopting MAKE and BUY together; θ_0 is constant. The condition for supermodularity now simplifies to:

$$\theta_{bm} = \theta_{11} + \theta_{00} - \theta_{10} - \theta_{01} > 0 \tag{7}$$

It is worth noting under (5) the marginal returns to either MAKE or BUY will not be constant anymore if complementarity or substitutability is observed ($\theta_{bm} \neq 0$). Henceforth, the marginal returns of MAKE and BUY should be expressed respectively as

$$\begin{aligned} [f \mid y_m = 1] - [f \mid y_m = 0] &= \theta_m + \theta_{bm} y_b \\ [f \mid y_b = 1] - [f \mid y_b = 0] &= \theta_b + \theta_{bm} y_m \end{aligned}$$

Athey and Stern (1998) explain that simply running OLS on the above function would deliver inconsistent results. They argue that the existence of firms' unobserved heterogeneity correlated with the strategy decisions may make the PROD approach fail to generate consistent estimators.

In order to correct for this bias, one should either use instrument variables with cross sectional data or neutralize the unobserved heterogeneity if panel data are available (Wooldridge, 2002). Cassiman and Veugelers (2006) have tried to adopt instrumental variables that were correlated with the adoption decisions without affecting innovation output. However, the results can be refined only if the instrumental variables are properly identified. In the current case, neither the input price (especially for BUY) that each firm faces in adopting innovation practices nor factors that affect the return to those practices are observed by the econometrician.

In the following part, we introduce another approach of testing for complementarity, which was originally developed by Miravete and Pernías (2006 and 2010) and later extended in Kretschmer, Miravete and Pernías (2012). This approach tests for "behavioural complementarity" and can be classified somewhere between the PROD approach introduced above and what is known in the literature as the CORR approach. The latter tests whether there remains a correlation between the error terms of the reduced forms of two strategy equations, which are derived without necessarily specifying any objective function. In contrast, in the Miravete and Pernías (MP) approach we specify an objective function, although in the end the estimation is based on the parameterization of the individual returns of each strategy.[3] Compared to the PROD approach we model explicitly the endogeneity of the strategy choices[4]. Apart from not specifying an objective function, the CORR approach imposes two assumptions: firms are assumed to make rational choices and there are no correlations between the unobserved factors that affect the activities concerned. The MP approach differs from the CORR approach by releasing the second assumption.

[3] In Kretschmer, Miravete and Pernías (2012) the objective function is estimated together with the strategy choice equations.

[4] The simple version is using the Pearson correlation or conditional correlation between the residuals to test for the association between two or more activities. A number of empirical studies use this approach as auxiliary evidence. For example: Arora and Gambardella (1990) introduce a formal analysis of (CORR) as a test for complementarity. Brickley (1995) explicitly uses (CORR) as a test for the comparative static predictions of Holmström and Milgrom (1994) in the context of franchising contract provisions. A critical assumption underlying this approach is the absence of covariance between the residuals of the strategy equations conditional on the characteristics of the firm.

Here, we start from the production function (8) by introducing both observed and unobserved factors, W_{ji} and ε_{ji} respectively, which are both interacted with input strategies MAKE and BUY in determining the productivity performance. The W_{ji} (j=b,m) are observed factors, which capture things like the firms' past innovation experience and its absorptive capacity, that can influence the return from the corresponding innovation strategy. Control variables are defined differently in determining the return of MAKE and BUY in order to avoid the identification problem. The ε_{ji}'s (j=b,m) capture unobserved factors that can influence the choice of MAKE and/or BUY, such as the appropriation regime or management practices, and factors that cannot be quantitatively or qualitatively identified. The production function is now given as

$$q = \alpha k_i + \beta l_i + (\theta_b W_{bi} + \delta_{bm} y_{mi} + \varepsilon_{bi}) y_{bi} + (\theta_m W_{mi} + \delta_{bm} y_{bi} + \varepsilon_{mi}) y_{mi} + \chi Z_i + e_i \tag{8}$$

Let

$$\lambda_{bi} = \theta_b W_{bi}; \lambda_{mi} = \theta_m W_{mi} \tag{9}$$

On the right-hand side of equation (8), $(\lambda_{bi} + \delta_{bm} y_{mi} + \varepsilon_{bi})$ and $(\lambda_{mi} + \delta_{bm} y_{bi} + \varepsilon_{mi})$ measure respectively the percentage differences in productivity level when choosing 1 instead of 0 for each of the two strategies, holding the other one fixed. Specification (8) is borrowed from Lewbel (2007). He shows that a specification like (8) eliminates the incoherency and incompleteness problems in simultaneous equations with binary variables, by specifying as an objective function that incorporates the individual returns derived from each individual strategy. Equation (8) differs from the PROD approach in that it captures not only the possible interaction between the input strategy variables and the technological capability λ_{ji}, but also the potential endogeneity of the strategy choices by including ε_{ji}, which is possibly correlated with y_{ji}. The existence of complementarity can only be concluded when controlling for both observed and unobserved characteristics.

We shall estimate equation (8) by maximum likelihood. Before we derive the likelihood function, two important assumptions need to be made. Because of the absence of information regarding the cost associated to the two innovation strategies, we are not able to derive a cost function, hence we assume that firms behave optimally by maximizing their productivity. Second, in order to avoid an identification problem, we assume that the unobserved error terms (ε_{bi}, ε_{mi}) follow a standard normal bivariate distribution with a correlation coefficient ρ_{bm}.

The firm has to decide on whether to adopt or not each of the two innovation strategies (MAKE and/or BUY). Therefore, four choice combinations are possible: D(1,1), D(1,0), D(0,1), D(0,0). The firm will choose the combination that yields the highest productivity. For each of the four possible choices we will get a corresponding set of inequality restrictions as follows[5]:

$$
\begin{aligned}
D_{(1,1)} &\Rightarrow \begin{Bmatrix} f(1,1) > f(0,1) \\ f(1,1) > f(1,0) \\ f(1,1) > f(0,0) \end{Bmatrix} = \begin{Bmatrix} \varepsilon_{bi} > -\lambda_{bi} - 2\delta_{bm} \\ \varepsilon_{mi} > -\lambda_{mi} - 2\delta_{bm} \\ \varepsilon_{mi} > -\lambda_{bi} - \lambda_{mi} - 2\delta_{bm} - \varepsilon_{bi}\,* \end{Bmatrix} \\
D_{(1,0)} &\Rightarrow \begin{Bmatrix} f(1,0) > f(1,1) \\ f(1,0) > f(0,1) \\ f(1,0) > f(0,0) \end{Bmatrix} = \begin{Bmatrix} \varepsilon_{mi} < -\lambda_{mi} - 2\delta_{bm} \\ \varepsilon_{mi} < \lambda_{bi} - \lambda_{mi} + \varepsilon_{bi}\,* \\ \varepsilon_{bi} > -\lambda_{bi} \end{Bmatrix} \\
D_{(0,1)} &\Rightarrow \begin{Bmatrix} f(0,1) > f(1,1) \\ f(0,1) > f(1,0) \\ f(0,1) > f(0,0) \end{Bmatrix} = \begin{Bmatrix} \varepsilon_{bi} < -\lambda_{bi} - 2\delta_{bm} \\ \varepsilon_{mi} > \lambda_{bi} - \lambda_{mi} + \varepsilon_{bi}\,* \\ \varepsilon_{mi} > -\lambda_{mi} \end{Bmatrix} \\
D_{(0,0)} &\Rightarrow \begin{Bmatrix} f(0,0) > f(1,1) \\ f(0,0) > f(1,0) \\ f(0,0) > f(0,1) \end{Bmatrix} = \begin{Bmatrix} \varepsilon_{mi} < -\lambda_{bi} - \lambda_{mi} - 2\delta_{bm} - \varepsilon_{bi}\,* \\ \varepsilon_{bi} < -\lambda_{bi} \\ \varepsilon_{mi} < -\lambda_{mi} \end{Bmatrix}
\end{aligned}
\tag{10}
$$

If D(1,1) is the optimal choice, the first set of inequality restrictions in (10) automatically satisfy the supermodular condition (1). This can be proved by:

First, adding the first two inequality for D(1,1) in (10), we will have

$$\varepsilon_{bi} + \varepsilon_{mi} + \lambda_{bi} + \lambda_{mi} + 4\delta_{bm} > 0\,; \tag{11}$$

then rearranging the third inequality of D(1,1) and putting the left sequence to the right,

$$\varepsilon_{bi} + \varepsilon_{mi} + \lambda_{bi} + \lambda_{mi} + 2\delta_{bm} > 0\,; \tag{12}$$

finally, subtracting (12) from (11), we obtain the supermodularity condition

[5] $f(y_{bi}, y_{mi})$ is derived from equation 8. Here, the form of D(1,1) is the sum of returns in choosing both MAKE and BUY: $(\lambda_{bi} + \delta_{bm} y_{mi} + \varepsilon_{bi})$ + $(\lambda_{mi} + \delta_{bm} y_{bi} + \varepsilon_{mi})$. This specific form for D(1,1) enables us to avoid the incoherency and incompleteness problems (Lewbel, 2007).

$$D(1,1) - D(1,0) > D(0,1) - D(0,0)$$
$$\Rightarrow (\lambda_{bi} + \delta_{bm} + \varepsilon_{bi}) + (\lambda_{mi} + \delta_{bm} + \varepsilon_{mi}) - (\lambda_{bi} + \varepsilon_{bi}) > (\lambda_{mi} + \varepsilon_{mi}) - 0 \Rightarrow 2\delta_{bm} > 0 \tag{13}$$

In the structural from, firms need to reach decisions by considering both the expected returns of doing MAKE/BUY and their possible synergy. If there is a synergistic effect, firms will engage in both activities together and we expect to see the existence of complementarity, which will be exhibited as $2\delta_{bm} > 0$. What is important to notice is that the estimation will control for the presence of the correlation between error terms, ρ_{bm}, which may cause the two strategies to be adopted jointly but for other reasons than complementarity between them.

In order to write the likelihood function, there are three situations that should be considered separately. First, if $\delta_{bm} = 0$, which implies that there is no complementarity between MAKE and BUY, (10) will be transformed into a likelihood function that corresponds to the standard bivariate probit model. There is no interaction between the returns of individual strategies, and hence each strategy is separately chosen depending on whether its return is above a certain threshold. Second, if $\delta_{bm} > 0$, the inequalities for D(1,1) and D(0,0) in (10) that are marked with an asterisk are binding. Last, if $\delta_{bm} < 0$, it is the inequalities marked with an asterisk for D(1,0) and D(1,0) in (10) that are binding.

The likelihood function will reproduce the probability of observing pairs of strategies that are determined by the inequality constraints in (10).

$$L_i(\alpha, \beta, \chi, \theta_b, \theta_m, \delta_{bm}, \rho_{bm}; y_{bi}, y_{mi}, Z_i)$$
$$= \sum_{i=1}^{n} \left\{ y_{bi} y_{mi} \ln P_{(1,1)} + y_{bi}(1 - y_{mi}) \ln P_{(1,0)} + (1 - y_{bi}) y_{mi} \ln P_{(0,1)} + (1 - y_{bi})(1 - y_{mi}) \ln P_{(0,0)} \right\}$$
(14)

where

$$P_{(1,1)} = \int_{-\lambda_{bi}-2\delta_{bm}}^{\infty} \int_{\max[(-\lambda_{mi}-2\delta_{bm}),(-\lambda_{bi}-\lambda_{mi}-2\delta_{bm}-\varepsilon_{bi})]}^{\infty} \phi_2(\varepsilon_{bi}, \varepsilon_{mi}, \rho_{bm}) d\varepsilon_{bi} d\varepsilon_{mi}$$

$$P_{(1,0)} = \int_{-\lambda_{bi}}^{\infty} \int_{-\infty}^{\min[(-\lambda_{mi}-2\delta_{bm}),(\lambda_{bi}-\lambda_{mi}+\varepsilon_{bi})]} \phi_2(\varepsilon_{bi}, \varepsilon_{mi}, \rho_{bm}) d\varepsilon_{bi} d\varepsilon_{mi}$$

$$P_{(0,1)} = \int_{-\infty}^{-\lambda_{bi}-2\delta_{bm}} \int_{\max[(-\lambda_{mi}),(\lambda_{bi}-\lambda_{mi}+\varepsilon_{bi})]}^{\infty} \phi_2(\varepsilon_{bi}, \varepsilon_{mi}, \rho_{bm}) d\varepsilon_{bi} d\varepsilon_{mi}$$

$$P_{(0,0)} = \int_{-\infty}^{-\lambda_{bi}} \int_{-\infty}^{\min[(-\lambda_{bi}),(-\lambda_{bi}-\lambda_{mi}+2\delta_{bm}-\varepsilon_{bi})]} \phi_2(\varepsilon_{bi}, \varepsilon_{mi}, \rho_{bm}) d\varepsilon_{bi} d\varepsilon_{mi}$$

where $P_{(1,1),}$ for instance, denotes the probability of observing the strategy pair (1,1). The same goes for the other pairs. In addition to the parameters in the production function (8), the correlation coefficient ρ_{bm} will also be estimated. The estimation of a truncated bivariate probit with upper and lower bounds is achieved by adopting the maximum simulated likelihood estimator using the GHK simulator (Hajivassiliou and Ruud, 1994; Greene, 2003).

4. Data and variables

4.1 Data

The data that we use in our empirical analysis come from the World Bank Investment Climate Surveys (ICS)[6]. These surveys have been conducted mostly in developing countries and provide us a wide range of information about innovative performance, economic activities and the investment environment of firms. Several aspects referring to firms' innovation behaviour are covered in the survey, such as firms' R&D input, licensing and other external sourcing channels.

After removing missing values and cleaning for outliers, we are left with 9,086 firms across 24 countries in the manufacturing sector in the pooled cross-sectional dataset from the period 2002-2005[7]. Due to differences in the size of the economies and the survey

[6] For more information and the methodology of the survey, please see http://www.worldbank.org

[7] We did not use the standardized dataset provided by the World Bank due to inconsistencies in the questionnaires and measurements (e.g. currencies). Instead, we cleaned the data country by country because the standardized dataset does not always cover all the information provided by firms. Additionally, the currency unit in the standardized data also caused some confusion, which needed to be traced back to each country's questionnaire. Furthermore, the service sector is not included because the innovation inputs (R&D and external sourcing) are not reported. Furthermore, following Hall and Mairesse (1995), we only keep observations for which the capital-labour ratio was within three times the inter-quartile range (the

methods adopted across countries and regions, the number of firms in the samples varies considerably across countries. Only countries with more than 50 observations are included [8]. Table 1 presents descriptive statistics about the countries and their innovativeness. Innovativeness here means having introduced a product or a process innovation.

<Insert table 1 here>

As shown in table 1, innovation is rather pervasive across countries with approximately 58 per cent of them claiming to have been innovative during the period under review. It should be noted again that these numbers do not represent inventions or introductions of products or processes new to the market. They are more likely to be innovations new to the firm, sometimes considered as imitative innovations. Among all countries in our sample, Brazil is the most innovative country with 86 per cent of firms having had product or process innovations in the period under review. In second place comes South Africa with 82 per cent. Ethiopia and Pakistan have no information with respect to innovation output[9].

The survey contains two main questions regarding firms' knowledge acquisition strategies. First, firms were asked to choose the three most important methods of knowledge sourcing out of a total of twelve options. The dummy variable BUY gets value 1 if firms chose at least one of the following three technological sources: importing machinery and equipment, hiring key personnel or licensing from abroad or domestically. Second, the survey has question related to firms' R&D spending in the last year of the survey period. R&D expenditures covers all outlays (labour costs, materials, expenditures on tangible fixed assets) incurred for research activities that comprise "creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications" (OECD, 2011). The dichotomous variable MAKE takes value 1 if firms claim to have positive R&D spending during the period of the survey, 0 otherwise.

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difference between the 75% value and the 25% value) above or below the median, which is about 6 percentage of total sample.

[8] A sample with less than 50 observations is unlikely to give us consistent estimates of the country specific effect. We also dropped firms with its number of permanent employee lower than 5 and the growth of sales per person greater than 300 percent. In total we eliminated in this way about 3% of all the observations.

[9] This is not problematic since innovation output will not be addressed in the following analysis. Our main concern is the productivity performance.

<Insert table 2 here>

Table 2 shows the count statistics of the appearance of each strategy and their interactions. We do not distinguish between higher- and lower-middle income countries, only between the union of those two and low-income countries. The statistics show that the main technology sourcing in low- and middle-income countries is external. Given the low levels of financial and human resources, firms seek innovation sources from external channels. There is about a 9 per cent higher frequency in pursuing the non-exclusive BUY strategy and a slightly lower probability of adopting the non-exclusive MAKE strategy in middle-income compared to low-income countries. Turning to the exclusive strategies (columns 3 to 6), we see that firms are more likely to adopt MAKE and BUY in middle-income than in low-income countries, 21.8 per cent versus 17.5 per cent. At a relatively higher level of development firms have probably accumulated some knowledge stocks and have gained experience that make them capable of doing in-house R&D and external BUY simultaneously. One should note that there are also other existing knowledge sourcing strategies, such as knowledge transfer from mother companies, learning from international conferences or study trips. We will not address these strategies here.

4.2 Specification of the production function

Table 3 provides the definition for each variable used in our empirical analysis.

<Insert Table 3 here>

Two sets of variables will be introduced in accordance with the two methods adopted in the empirical analysis, one for the PROD approach and the other one is for the MP approach. The dependent variable in the PROD approach is productivity, measured by sales per employee, in natural logarithmic terms. The standard explanatory variables in the production function (5) are: physical capital (total end-of-year capital per person in logs), labour (log of permanent workers at the end of the year). Sales and capital are converted in 1000 USD. Besides the standard explanatory variables, we also control for differences in capacity utilization (in percentage) because firms are likely to be more productive with the same amount of inputs when they operate at a relatively high level of capacity utilization.

Variable Export indicates whether firms had positive export sales during the last year. Here, we use Export to indicate the level of openness of the economy. Openness has generally led to greater competition in the product markets and increasingly also in the markets for services. More vigorous competition exerts discipline on firms in developing countries. It therefore tends to strengthen incentives for development in their economy. So we expect a positive relation between export activities and firm performance.

The ICS survey contains a series of information about the business environment in which firms operate. The business environment consists of government regulations, institutional background, or social conventions, which are believed to have a substantial impact on firms' production decisions and performance (Coase, 1998). Questions are asked about obstacles to innovation on a four-point Likert scale. We select the infrastructure, regulation, and financial innovation hindrances and transform these variables in binary variables. The dummy variables Infra_obs, Regu_obs and Finance_obs take value 1 if the answer is marked as a major or very severe obstacle (scores 3 and 4). It is believed that these economic and institutional obstacles can play a significant role in explaining the heterogeneous performance in productivity across countries (Mohnen and Röller, 2005). Size[10], industry and country dummies[11] are used to capture the heterogeneities due to size, industries and countries.

4.3 Specification of the knowledge acquisition equations

Two categories of variables are expected to affect firms' knowledge sourcing strategies. The first category is firm specific. It includes size and foreign ownership (Foreign-owner). Larger firms are expected to be more innovative and hence have more often internal R&D activities and external technology purchases. Most of the foreign firms in developing countries are more competitive than the domestic firms. However, empirical evidence has shown that in joint ventures the core technologies remain generally under the control of the foreign partners or company headquarters abroad (OECD, 2007). So, in general, foreign-owned companies are expected to be less likely to engage in innovation activities than domestic firms.

The second category of variables is intended to capture the technological capability that affects firms' innovation strategy decisions. Because information technology is commonly recognized as an important technological infrastructure to improve communication and logistics efficiency, IT is included in both the returns of both MAKE and BUY. Dummy variable ISO with value 1 indicates that the firm has received international certificates, for

[10] Small firms: < 20 employees; medium size firms: 21-99 employees, large size firms > 100 employees.
[11] Four regions are included: European, African, Asian and Latin American countries.

example ISO9000, ISO9002 or ISO14000. ISO standards in general represent a reservoir of technology. In developing countries, ISO standards are important means both of acquiring technological know-how and of raising the capability to compete in global markets. ISO certifications to some extent reflect the technological capability and experience of firms. Training will be included only in the MAKE function. It gets value 1 if firms carry out a training program for their employees. Skilled labour is an essential part of firms' innovation capacity to accommodate and integrate the new knowledge into production and ultimately transform it into new products or processes. Dummy variable Edu_manager has a value 1 if the average education level of senior managers is above the university level. It will only be included in the BUY equation.

Dummy variable Co_supply/customer indicates collaboration with suppliers and customers, which is believed to be associated with input quality improvements aimed at cost reductions or market expansion (Von Hippel, 1988; Tether, 2002). Co_university indicates if firms cooperate with universities and research institutes. It is generally associated with radical, breakthrough innovations that may open up entire new markets or market segments (Tether, 2002; Monjon and Waelbroeck, 2003). These two indicators are also widely used to measure a firm's absorptive capacity (Zahra and George, 2002; Schmidt, 2005; Freel and Harrison, 2006).

<Insert figure 1 here>

Figure 1 depicts the differences in the mean values of the explanatory variables between low- and middle-income countries. Clearly, technological capability and institutional environment are heterogeneous across levels of development. The pattern exhibits that the mean values of technology-related variables are generally higher in middle-income than in the low-income countries. One exception in our sample is the managers' education that is higher in the low-income group, which might be due to the differences in the education system across countries.

It is worth to highlight the pattern of technological capability across different income groups here. Lane and Lubatkin (1998) suggest that firms learn from firms that have similar characteristics. Dussauge et al. (2000) and Cohen and Levinthal (1990) use the path-dependency theory to conclude that a firm is better able to acquire and use knowledge sourcing if it has some prior experience or higher technological capability. With low levels of development firms might be constrained by generally low levels of technological capability. Hence, firms in low-income countries might rely mainly on external technology acquisitions. Additionally, the synergy effect of MAKE_and_BUY on productivity performance will be undermined by factors such as weak infrastructure, scarce financial resources, etc. The increase of technological capability will catalyse the speed and efficiency of absorbing external know-how; hence we argue that the complementarity between in-house and external knowledge sourcing strategies is expected to appear as the level of development increases. The last three columns in figure 1 show the mean values of the infrastructure, financial and regulation obstacles that firms face. At least the infrastructure and finance related obstacles are more severely felt in low-income countries.

5. Empirical results

This section discusses the result of empirical analysis of the role of technology sourcing strategies in affecting firms' performance. Importantly, we would like to see whether there are synergistic effects between them. As shown in table 4, a simple correlation between MAKE and BUY regardless of any other differences in firms' characteristics gives a Pearson coefficient of -0.0017 (non-significant at 10%) for the low-income countries and 0.1167 (significant at 1%) for the middle-income countries. This finding suggests an association between innovation sourcing strategies in middle-income countries. However, as stated before, the correlation observed here may be caused by the firm specifics. It is unwarranted to draw a conclusion at this stage.

<Insert table 4 here>

5.1 PROD approach

Based on equation 5, we regress firms' productivity (in logarithm) on the innovation strategies MAKE and BUY while controlling for other firm, industry and country specificities, which may affect the productivity performance. The results are given in table 5.

<Insert table 5 here>

We separate the sample into two groups according to their income levels. The first two columns of table 5 are the results without interaction term between MAKE and BUY while the last two columns include it. Except for the technological sourcing variables, the estimated coefficients of the other variables do not differ considerably when controlling or not for the interaction term.

As shown in table 5, different patterns are observed across different income levels with respect to the determinants of productivity performance. The findings suggest that the elasticity of capital stock (Capital) to productivity is positive and does not differ considerably, 0.44 and 0.46 respectively for low- and middle-income countries. We found that there are in general increasing returns to scale in middle-income countries and, on the contrary, decreasing returns to scale in the low-income group at a 95 per cent significant level. Firms with higher utilization of resources and production capacity are more productive in both groups, and it is reflected by the highly significant coefficients of Capacity.

Not surprisingly, when firms face severe obstacles in their production process, their production performance is likely to be hampered or delayed and the productivity performance is expected to be lower. Financial constrains (Finance_obs) depress productivity of firms in both groups, especially in the low-income countries, the estimated coefficient being -0.153 and -0.105 respectively. Infra_obs does not differ significantly from zero for both groups. The estimated coefficients of Regu_obs show a positive impact on the productivity across firms in middle-income countries. It might due to the fact that firms that face more regulations are more likely to spend more time in dealing with the regulation authorities (Mohnen and Röller, 2005). As a result, they may learn how to overcome these barriers more efficiently and benefit in terms of productivity performance. It may also be that obstacles are better perceived by more innovating firms, in which case obstacles might reflect innovation with more innovating firms being more productive. Exporting firms in low- and middle-income countries are respectively 54.8 per cent and 20.5 per cent more productive than non-exporting firms. Entering international markets enables these firms to boost their productivity by interacting with buyers and also by coping with intensive competition in the export market.

Regarding the effect of innovation sourcing strategies in firms' performance, the results of table 5 present us the marginal contribution of MAKE, BUY and their interaction effect. Regardless of whether the interaction term is included or not, the estimators for BUY are all positive and significant in both groups. Especially for low-income countries, firms adopting external technological sourcing are more productive compared to those that participate in in-house R&D and those that are not involved in any innovation investment.

The result implies that in the context of a low level of development, firms investing in innovation through external channel are more productive and external sourcing strategies play a critical role in contributing to their performance. However, in the case of middle-income countries, in-house R&D becomes significant.

Turning to the potential synergistic effects between MAKE and BUY, the last two columns of table 5 show that interaction coefficients of MAKE and BUY are not significant in both groups. This result suggests that there is no complementarity observed between MAKE and BUY in fostering productivity. The return of adopting in-house R&D and external technology buying together does not differ from the sum of the returns from adopting them individually. Assuming there are no unobserved factors across firms, we can conclude at this stage that no complementarity is confirmed between MAKE and BUY. With the presence of an interaction term, external sourcing still plays a significant role across low-income countries while investing in in-house R&D seems to be more efficient in fostering productivity improvements across firms in middle-income countries.

Practically, it is very difficult for economists to identify and control all the possible sources of heterogeneity across firms. So far our estimations of complementarity (or substitutability) are based on the assumption that no unobserved heterogeneities exist in the returns to MAKE and BUY. This assumption will be released in the next section. The Miravete and Pernías approach will enable us to distinguish complementarity and the association due to unobserved heterogeneity.

5.2 The Miravete and Pernías approach

The first two columns of Table 6 give the bivariate probit results of conditional correlation between internal and external innovation sourcing. The bivariate probit analysis assumes no synergy ($\delta_{bm} = 0$ in equation (8)). After controlling for observed heterogeneities, the magnitude of the correlation coefficients between MAKE and BUY decisions do not differ much from those the simple Pearson correlation coefficients that we obtained at the beginning of our analysis.

<Insert table 6 here>

The last two columns of Table 6 report the results from MP approach. In the presence of complementarity and correlation due to unobserved heterogeneities, the estimated coefficients of the exogenous variables are in line with those of the bivariate probit estimation but slightly different in magnitudes. In the interpretation underlying equation (8) these variables explain the adoption of MAKE and BUY and their marginal returns.

The firm specific factors have a significant influence on firms' knowledge sourcing strategies. Firms with more employees seem to be more motivated to participate in both in-house and external innovating activities. Large firms are likely to have more resources to dedicate to innovation activities. Since in joint ventures technologies remain controlled by the foreign company headquarters abroad, foreign-invested companies are reluctant to engage in innovation activities by themselves. The estimated coefficients of Foreign-owner are negative but only significant in affecting MAKE for the group of middle-income countries.

Firms with more technological capability are more profitable in adopting either of the innovation strategies. This effect can be reflected by the coefficients of technological variables. In the middle-income countries, IT and Edu_manager are positively correlated with BUY whereas IT and Training encourage firms to adopt in-house R&D. ISO coefficients are not significant anywhere and for the low-income group, none of the technological indictors is significant. Cooperative activities, (Co_supplier/customer and Co_university) are observed to stimulate firms' MAKE decision in the middle-income countries and to reduce the purchase of external knowledge in the low-income countries. Collaboration seems to enhance knowledge, encourage own R&D efforts and reducing the need for external knowledge, substituting in a sense for technology purchasing. After including the complementarity coefficient in the system, the correlation coefficient between residuals is unchanged and insignificant in the low-income countries as it shown in δ_{bm}, the correlation coefficient between the unobserved effects remains, insignificant in the low-income countries and becomes negative in the middle-income countries. No sign of complementarity exists in low-income countries. However, in the meddle-income countries the complementarity coefficient is positive and statistically significant at the 99 per cent confidence level. Hence in those countries it pays to do both MAKE and BUY simultaneously as is generally found in developed countries.

6. Conclusion

The lack of advanced technological competencies in developing countries requires innovation to occur through the absorption of existing knowledge and the adoption of existing technologies. In the low-income countries, the low levels of technological capability severely constrains firms in their efforts to build up their own R&D stock of knowledge and make them rely instead on external knowledge acquisitions such as licensing, hiring skilled labour and purchasing technology embedded in machinery and collaborating with foreign firms. Our results highlight the significant contribution of external technological sourcing for productivity performance in the low-income countries. In the middle-income countries it is the combination of internal R&D and external knowledge acquisition that leads to a better productivity performance.

These findings suggest that at different levels of development, governments formulate different policies in order to achieve optimal productivity performance. At a low level of development, external sourcing strategies are essential for local firms to integrate the global market. Governments should develop policies that encourage external sourcing, such as providing technological information and financial support for technology import. In middle-income countries, where firms have sufficiently built up their technological capabilities and gathered some innovation experience, government policies should focus on encouraging firms to invest in both internal and external technological sourcing because of the existence of a complementarity between them.

Appendix: Likelihood function

(A1) $l_i(y_{bi}, y_{mi}) = \int\limits_{S(y_{bi}, y_{mi})} \phi_2(\frac{\varepsilon_{bi}}{\sigma_b}, \frac{\varepsilon_{mi}}{\sigma_m}; -s_i\rho_{bm}) d\frac{\varepsilon_{mi}}{\sigma_m} d\frac{\varepsilon_{bi}}{\sigma_b}$

We normalize the standard deviations of y_{bi} and y_{mi} to be equal to 1, $\sigma_b = \sigma_m = 1$. Hence, the likelihood function can be written as follows:

1) when δ=0, the likelihood function will be correspond to the likelihood function of a standard bivariate probit

(A2) $l_i(y_{bi} = 1, y_{mi} = 1) = \int_{\frac{-\lambda_{bi}}{\sigma_b}}^{+\infty} \int_{\frac{-\lambda_{mi}}{\sigma_m}}^{+\infty} \phi_2(\frac{\varepsilon_{bi}}{\sigma_b}, \frac{\varepsilon_{mi}}{\sigma_m}; -s_i\rho_{bm}) d\frac{\varepsilon_{mi}}{\sigma_m} d\frac{\varepsilon_{bi}}{\sigma_b}$

$= \Phi_2(\frac{\lambda_{bi}}{\sigma_b}, \frac{\lambda_{mi}}{\sigma_m}; \rho_{bm})$

(A3) $l_i(y_{bi} = 0, y_{mi} = 0) = \int_{\frac{\lambda_{bi}}{\sigma_b}}^{+\infty} \int_{\frac{\lambda_{mi}}{\sigma_m}}^{+\infty} \phi_2(\frac{\varepsilon_{bi}}{\sigma_b}, \frac{\varepsilon_{mi}}{\sigma_m}; -s_i\rho_{bm}) d\frac{\varepsilon_{mi}}{\sigma_m} d\frac{\varepsilon_{bi}}{\sigma_b}$

$= \Phi_2(\frac{-\lambda_{bi}}{\sigma_b}, \frac{-\lambda_{mi}}{\sigma_m}; \rho_{bm})$

(A4) $l_i(y_{bi} = 1, y_{mi} = 0) = \int_{\frac{-\lambda_{bi}}{\sigma_b}}^{+\infty} \int_{\frac{\lambda_{mi}}{\sigma_m}}^{+\infty} \phi_2(\frac{\varepsilon_{bi}}{\sigma_b}, \frac{\varepsilon_{mi}}{\sigma_m}; -s_i\rho_{bm}) d\frac{\varepsilon_{mi}}{\sigma_m} d\frac{\varepsilon_{bi}}{\sigma_b}$

$= \Phi_2(\frac{\lambda_{bi}}{\sigma_b}, \frac{-\lambda_{mi}}{\sigma_m}; -\rho_{bm})$

(A5) $l_i(y_{bi} = 0, y_{mi} = 1) = \int_{\frac{\lambda_{bi}}{\sigma_b}}^{+\infty} \int_{\frac{-\lambda_{mi}}{\sigma_m}}^{+\infty} \phi_2(\frac{\varepsilon_{bi}}{\sigma_b}, \frac{\varepsilon_{mi}}{\sigma_m}; -s_i\rho_{bm}) d\frac{\varepsilon_{mi}}{\sigma_m} d\frac{\varepsilon_{bi}}{\sigma_b}$

$= \Phi_2(\frac{-\lambda_{bi}}{\sigma_b}, \frac{\lambda_{mi}}{\sigma_m}; -\rho_{bm})$

2) when δ < 0, inequalities marked with an asterisk of D(1,0) and D(1,0) in (10) are binding. The probability distribution will no longer be rectangular as the case of a bivariate probit.

(A6) $l_i(y_{bi} = 1, y_{mi} = 1) = \int_{\frac{-\lambda_{bi}-2\delta}{\sigma_b}}^{+\infty} \int_{\frac{-\lambda_{mi}-2\delta}{\sigma_m}}^{+\infty} \phi_2(\frac{\varepsilon_{bi}}{\sigma_b}, \frac{\varepsilon_{mi}}{\sigma_m}; -s_i\rho_{bm}) d\frac{\varepsilon_{mi}}{\sigma_m} d\frac{\varepsilon_{bi}}{\sigma_b}$

$= \Phi_2(\frac{\lambda_{bi}+2\delta}{\sigma_b}, \frac{\lambda_{mi}+2\delta}{\sigma_m}; \rho_{bm})$

(A7) $l_i(y_{bi} = 0, y_{mi} = 0) = \int_{\frac{\lambda_{bi}}{\sigma_b}}^{+\infty} \int_{\frac{\lambda_{mi}}{\sigma_m}}^{+\infty} \phi_2(\frac{\varepsilon_{bi}}{\sigma_b}, \frac{\varepsilon_{mi}}{\sigma_m}; -s_i\rho_{bm}) d\frac{\varepsilon_{mi}}{\sigma_m} d\frac{\varepsilon_{bi}}{\sigma_b}$

$$= \Phi_2(\frac{-\lambda_{bi}}{\sigma_b}, \frac{-\lambda_{mi}}{\sigma_m}; \rho_{bm})$$

(A8)

$$l_i(y_{bi}=1, y_{mi}=0) = \int_{\frac{-\lambda_{bi}}{\sigma_b}}^{+\infty} \int_{\frac{\lambda_{mi}+2\delta}{\sigma_m}}^{+\infty} \phi_2(\frac{\varepsilon_{bi}}{\sigma_b}, \frac{\varepsilon_{mi}}{\sigma_m}; -s_i\rho_{bm}) d\frac{\varepsilon_{mi}}{\sigma_m} d\frac{\varepsilon_{bi}}{\sigma_b} - \int_{\frac{-\lambda_{bi}-2\delta}{\sigma_b}}^{\frac{-\lambda_{bi}}{\sigma_b}} \int_{\frac{-\lambda_{mi}-2\delta}{\sigma_m}}^{\frac{\lambda_{bi}-\lambda_{mi}+\varepsilon_{bi}}{\sigma_m}} \phi_2(\frac{\varepsilon_{bi}}{\sigma_b}, \frac{\varepsilon_{mi}}{\sigma_m}; -s_i\rho_{bm}) d\frac{\varepsilon_{mi}}{\sigma_m} d\frac{\varepsilon_{bi}}{\sigma_b}$$

$$= \Phi_2(\frac{\lambda_{bi}}{\sigma_b}, \frac{-\lambda_{mi}-2\delta}{\sigma_m}; -\rho_{bm}) - \int_{\frac{-\lambda_{bi}-2\delta}{\sigma_b}}^{\frac{-\lambda_{bi}}{\sigma_b}} \Phi(\frac{\varepsilon_{bi}}{\sigma_b})[\Phi(\frac{\lambda_{bi}-\lambda_{mi}+\varepsilon_{bi}}{\sigma_m}) - \Phi(\frac{-\lambda_{mi}-2\delta}{\sigma_m})] d\frac{\varepsilon_{bi}}{\sigma_b}$$

(A9)

$$l_i(y_{bi}=0, y_{mi}=1) = \int_{\frac{\lambda_{bi}+2\delta}{\sigma_b}}^{+\infty} \int_{\frac{-\lambda_{mi}}{\sigma_m}}^{+\infty} \varphi_2(\frac{\varepsilon_{bi}}{\sigma_b}, \frac{\varepsilon_{mi}}{\sigma_m}; -s_i\rho_{bm}) d\frac{\varepsilon_{mi}}{\sigma_m} d\frac{\varepsilon_{bi}}{\sigma_b} + \int_{\frac{-\lambda_{bi}-2\delta}{\sigma_b}}^{\frac{-\lambda_{bi}}{\sigma_b}} \int_{\frac{-\lambda_{mi}}{\sigma_m}}^{\frac{\lambda_{bi}-\lambda_{mi}+\varepsilon_{bi}}{\sigma_m}} \varphi_2(\frac{\varepsilon_{bi}}{\sigma_b}, \frac{\varepsilon_{mi}}{\sigma_m}; -s_i\rho_{bm}) d\frac{\varepsilon_{mi}}{\sigma_m} d\frac{\varepsilon_{bi}}{\sigma_b}$$

$$= \Phi_2(\frac{-\lambda_{bi}-2\delta}{\sigma_b}, \frac{\lambda_{mi}}{\sigma_m}; -\rho_{bm}) + \int_{\frac{-\lambda_{bi}-2\delta}{\sigma_b}}^{\frac{-\lambda_{bi}}{\sigma_b}} \Phi(\frac{\varepsilon_{bi}}{\sigma_b})[\Phi(\frac{\lambda_{bi}-\lambda_{mi}+\varepsilon_{bi}}{\sigma_m}) - \Phi(\frac{-\lambda_{mi}}{\sigma_m})] d\frac{\varepsilon_{bi}}{\sigma_b}$$

3) when δ > 0, inequalities marked with an asterisk of D(1,1) and D(0,0) in (10) are binding.

(A10)

$$l_i(y_{bi}=1, y_{mi}=1) = \int_{\frac{-\lambda_{bi}-2\delta}{\sigma_b}}^{+\infty} \int_{\frac{-\lambda_{mi}-2\delta}{\sigma_m}}^{+\infty} \phi_2(\frac{\varepsilon_{bi}}{\sigma_b}, \frac{\varepsilon_{mi}}{\sigma_m}; -s_i\rho_{bm}) d\frac{\varepsilon_{mi}}{\sigma_m} d\frac{\varepsilon_{bi}}{\sigma_b} - \int_{\frac{-\lambda_{bi}-2\delta}{\sigma_b}}^{\frac{-\lambda_{bi}}{\sigma_b}} \int_{\frac{-\lambda_{mi}-2\delta}{\sigma_m}}^{\frac{-\lambda_{bi}-\lambda_{mi}-2\delta-\varepsilon_{bi}}{\sigma_m}} \phi_2(\frac{\varepsilon_{bi}}{\sigma_b}, \frac{\varepsilon_{mi}}{\sigma_m}; -s_i\rho_{bm}) d\frac{\varepsilon_{mi}}{\sigma_m} d\frac{\varepsilon_{bi}}{\sigma_b}$$

$$= \Phi_2(\frac{\lambda_{bi}+2\delta}{\sigma_b}, \frac{\lambda_{mi}+2\delta}{\sigma_m}; \rho_{bm}) - \int_{\frac{-\lambda_{bi}-2\delta}{\sigma_b}}^{\frac{-\lambda_{bi}}{\sigma_b}} \Phi(\frac{\varepsilon_{bi}}{\sigma_b})[\Phi(\frac{-\lambda_{bi}-\lambda_{mi}-2\delta-\varepsilon_{bi}}{\sigma_m}) - \Phi(\frac{-\lambda_{mi}-2\delta}{\sigma_m})] d\frac{\varepsilon_{bi}}{\sigma_b}$$ [12]

(A11)

$$l_i(y_{bi}=0, y_{mi}=0) = \int_{\frac{\lambda_{bi}}{\sigma_b}}^{+\infty} \int_{\frac{\lambda_{mi}}{\sigma_m}}^{+\infty} \varphi_2(\frac{\varepsilon_{bi}}{\sigma_b}, \frac{\varepsilon_{mi}}{\sigma_m}; -s_i\rho_{bm}) d\frac{\varepsilon_{mi}}{\sigma_m} d\frac{\varepsilon_{bi}}{\sigma_b} + \int_{\frac{-\lambda_{bi}-2\delta}{\sigma_b}}^{\frac{-\lambda_{bi}}{\sigma_b}} \int_{\frac{-\lambda_{mi}}{\sigma_m}}^{\frac{-\lambda_{bi}-\lambda_{mi}-2\delta-\varepsilon_{bi}}{\sigma_m}} \varphi_2(\frac{\varepsilon_{bi}}{\sigma_b}, \frac{\varepsilon_{mi}}{\sigma_m}; -s_i\rho_{bm}) d\frac{\varepsilon_{mi}}{\sigma_m} d\frac{\varepsilon_{bi}}{\sigma_b}$$

$$= \Phi_2(\frac{-\lambda_{bi}}{\sigma_b}, \frac{-\lambda_{mi}}{\sigma_m}; \rho_{bm}) + \int_{\frac{-\lambda_{bi}-2\delta}{\sigma_b}}^{\frac{-\lambda_{bi}}{\sigma_b}} \Phi(\frac{\varepsilon_{bi}}{\sigma_b})[\Phi(\frac{-\lambda_{bi}-\lambda_{mi}-2\delta-\varepsilon_{bi}}{\sigma_m}) - \Phi(\frac{-\lambda_{mi}}{\sigma_m})] d\frac{\varepsilon_{bi}}{\sigma_b}$$

(A12) $$l_i(y_{bi}=1, y_{mi}=0) = \int_{\frac{-\lambda_{bi}}{\sigma_b}}^{+\infty} \int_{\frac{\lambda_{mi}+2\delta}{\sigma_m}}^{+\infty} \phi_2(\frac{\varepsilon_{bi}}{\sigma_b}, \frac{\varepsilon_{mi}}{\sigma_m}; -s_i\rho_{bm}) d\frac{\varepsilon_{mi}}{\sigma_m} d\frac{\varepsilon_{bi}}{\sigma_b}$$

$$= \Phi_2(\frac{\lambda_{bi}}{\sigma_b}, \frac{-\lambda_{mi}-2\delta}{\sigma_m}; -\rho_{bm})$$

(A13) $$l_i(y_{bi}=0, y_{mi}=1) = \int_{\frac{\lambda_{bi}+2\delta}{\sigma_b}}^{+\infty} \int_{\frac{-\lambda_{mi}}{\sigma_m}}^{+\infty} \phi_2(\frac{\varepsilon_{bi}}{\sigma_b}, \frac{\varepsilon_{mi}}{\sigma_m}; -s_i\rho_{bm}) d\frac{\varepsilon_{mi}}{\sigma_m} d\frac{\varepsilon_{bi}}{\sigma_b}$$

$$= \Phi_2(\frac{-\lambda_{bi}-2\delta}{\sigma_b}, \frac{\lambda_{mi}}{\sigma_m}; -\rho_{bm})$$

Alternatively, the likelihood function can be written as:

---

[12] Equation 4.a10 could also be written as $\int_{-\infty}^{-\lambda_{bi}} \int_{-\infty}^{\min\{-\lambda_{mi}, -(\lambda_{bi}+\lambda_{mi}+2\delta+\varepsilon_{bi})\}} \phi_2(\frac{\varepsilon_{bi}}{\sigma_b}, \frac{\varepsilon_{mi}}{\sigma_m}; -s_i\rho_{bm}) d\frac{\varepsilon_{mi}}{\sigma_m} d\frac{\varepsilon_{bi}}{\sigma_b}$

(A14) $q_{ji} = 2y_{ji} - 1(j = b, m)$

(A15) $s_i = q_{bi} q_{mi}$

(A16) $v_i = (s_i + 1)/2$

(A17)
$$l_i(y_{bi}, y_{mi}) = \int_{\frac{-q_{bi}(\lambda_{bi}+2\delta y_{mi})}{\sigma_b}}^{+\infty} \int_{\frac{-q_{mi}(\lambda_{mi}+2\delta y_{bi})}{\sigma_m}}^{+\infty} \phi_2(\frac{\varepsilon_{bi}}{\sigma_b}, \frac{\varepsilon_{mi}}{\sigma_m}; s_i \rho_{bm}) d\frac{\varepsilon_{mi}}{\sigma_m} d\frac{\varepsilon_{bi}}{\sigma_b}$$
$$- q_{bi} * 1(s_i 2\delta > 0) \int_{\frac{-(\lambda_{bi}+2\delta)}{\sigma_b}}^{\frac{-\lambda_{bi}}{\sigma_b}} \int_{\frac{-(\lambda_{mi}+2\delta y_{bi})}{\sigma_m}}^{\frac{-(\lambda_{mi}+s_i\lambda_{bi}+v_i 2\delta+s_i\varepsilon_{bi})}{\sigma_m}} \phi_2(\frac{\varepsilon_{bi}}{\sigma_b}, \frac{\varepsilon_{mi}}{\sigma_m}; \rho_{bm}) d\frac{\varepsilon_{mi}}{\sigma_m} d\frac{\varepsilon_{bi}}{\sigma_b}$$

$$= \Phi_2(\frac{q_{bi}(\lambda_{bi} + 2\delta y_{mi})}{\sigma_b}, \frac{q_{mi}(\lambda_{mi} + 2\delta y_{bi})}{\sigma_m}; s_i \rho_{bm})$$
$$- q_b * 1(s_i 2\delta > 0) \int_{\frac{-(\lambda_{bi}+2\delta)}{\sigma_b}}^{\frac{-\lambda_{bi}}{\sigma_b}} \int_{\frac{-(\lambda_{mi}+2\delta y_{bi})}{\sigma_m}}^{\frac{-(\lambda_{mi}+s_i\lambda_{bi}+v_i 2\delta+s_i\varepsilon_{bi})}{\sigma_m}} \varphi_2(\frac{\varepsilon_{bi}}{\sigma_b}, \frac{\varepsilon_{mi}}{\sigma_m}; \rho_{bm}) d\frac{\varepsilon_{mi}}{\sigma_m} d\frac{\varepsilon_{bi}}{\sigma_b}$$

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Table 1 Innovativeness of firms in developing countries

Country	Year	Observ ation (firms)	Income[13]	Percentage of innovation	Output per worker (log, 1000 USD/person)	Capital per worker (log, 1000 USD/person)	Labour (log, person)
Brazil	2003	1463	Lower-Middle income	85.99%	2.58	2.03	4.00
Chile	2004	306	Higher-Middle income	51.31%	3.70	3.69	3.90
Costa Rica	2005	88	Higher-Middle income	78.41%	3.01	2.74	3.47
Ecuador	2003	273	Lower-Middle income	75.46%	2.92	2.71	3.67
Egypt	2004	582	Lower-Middle income	11.51%	1.47	1.46	3.37
El Salvador	2003	280	Lower-Middle income	80.71%	2.69	2.60	3.79
Ethiopia	2002	243	Low-income	missing	1.51	2.16	3.64
Guatemala	2003	371	Lower-Middle income	72.78%	2.41	2.19	3.58
Guyana	2004	97	Lower-Middle income	54.64%	2.52	2.73	3.09
Honduras	2003	323	Lower-Middle income	66.25%	2.19	1.98	3.28
Indonesia	2003	466	Lower-Middle income	46.35%	1.86	1.76	5.23
Lithuania	2004	74	Higher-Middle income	39.19%	2.18	0.94	3.79
Madagascar	2005	79	Low-income	60.76%	1.50	1.65	4.11
Malawi	2005	84	Low-income	64.29%	2.34	2.03	4.15
Mauritius	2005	98	Higher-Middle income	72.45%	2.70	2.40	4.12
Nicaragua	2003	308	Low-income	75.00%	1.77	1.73	2.95
Pakistan	2002	845	Low-income	missing	2.31	2.29	3.30
Philippines	2003	582	Lower-Middle income	59.79%	1.97	1.57	4.16
South Africa	2003	513	Lower-Middle income	82.85%	3.47	2.85	4.69
Syria	2003	75	Lower-Middle income	36.00%	1.83	2.70	2.23
Tanzania	2003	73	Low-income	49.32%	2.09	2.21	3.51
Thailand	2004	1336	Lower-Middle income	64.97%	2.85	2.49	4.96
Turkey	2005	454	Higher-Middle income	69.16%	3.54	3.32	4.20
Zambia	2002	73	Low-income	72.60%	2.54	2.24	4.07
Total		9086		57.67%	2.50	2.26	4.02

Table 2 "Make" and "buy" strategies in developing countries

Income level	MAKE	BUY	MAKE ONLY	BUY ONLY	MAKE AND BUY	NO MAKE OR BUY	Innovation
Low-income countries	31.09%	56.54%	13.55%	39.00%	17.54%	29.91%	24.75%
Middle-income countries	28.84%	67.05%	7.02%	45.22%	21.83%	25.93%	65.28%
Total	29.26%	65.08%	8.24%	44.06%	21.02%	26.68%	57.67%

[13] Countries are divided according to 2011 GNI per capita, calculated using the World Bank Atlas method (http://data.worldbank.org/about/country-classifications/world-bank-atlas-method). Low-income countries: 1,025 USD or less; lower middle-income countries: 1,026 - 4,035 USD; upper middle-income countries: 4,036 - 12,475 USD; and high-income countries: 12,476 USD or more.

Table 3 Definition of variables

Dependent variable		PROD	MP
PRODUCTIVITY	Total sales /Number of long-term permanent workers, in 1000USD, in logs	√	
Explanatory Variables			
Capital	Total assets of firms (including Property, Plant and Equipment)/Number of long-term permanent workers, in 1000 USD and in logs	√	
Labour	Number of long-term permanent workers	√	
Capacity	Actual output produced (1000 USD)/ Maximum output that could be produced with existing machinery and equipment and regular shifts (value between 0-1)	√	
Innovation strategy variable			
MAKE	Dummy variable equal to 1 if firms have own R&D activities and have a positive R&D budget	√	√
BUY	Dummy variable equal to 1 if firms acquire technology through at least one of the following external technology acquisition methods: importing machinery and equipment; hiring key personnel; licensing	√	√
Control variables			
Foreign_owner	Dummy variable equal to 1 if a firm has foreign ownership		√
Exporter	Dummy variable equal to 1 if firm's sales are exported		√
Edu_manager	Dummy variable equal to 1 if manager have graduate school or above education		√
Training	Dummy variable equal to 1 if training programme took place		√
IT	Dummy variable equal to 1 if firms use internet or have own website		√
ISO	Dummy variable equal to 1 if a firm has ISO (international certification)		√
Co-supply/customer	Dummy variable equal to 1 if a firm has cooperative innovation activities with suppliers or customers		√
Co_university	Dummy variable equal to 1 if a firm has cooperative innovation activities with universities		√
Finance_obs	Dummy variable with the value 1 if accessing to finance or costs of finance is a major obstacle to firm	√	
Infra_obs	Lost value of sales due to power outages during last operation year, in percentage	√	
Regu_obs	The average time of managers dealing with government regulations	√	
Industry dummy	Definition of industrial categories and Low-tech industries from OECD[14]	√	√
Country dummy	Countries included in our study	√	

[14] See http://www.oecd.org

Table 4 Unconditional correlations between innovation strategies and scale of investment

	Low-income countries		**Middle-income countries**	
	MAKE	**BUY**	**MAKE**	**BUY**
MAKE	1		1	
BUY	-0.0017	1	0.1167***	1

***indicates the results is significant at 0.01.

Table 5 PROD approach. OLS regression of equation (2) results without and with the interaction term

	Without interaction		With interaction	
Productivity	Low-income countries	Middle-income countries	Low-income countries	Middle-income countries
Capital	0.443***	0.469***	0.443***	0.468***
	0.020	*0.007*	*0.020*	*0.007*
Labour	-0.103**	0.064***	-0.102***	0.064***
	0.044	*0.016*	*0.044*	*0.016*
Capacity	0.517***	0.514***	0.522***	0.511***
	0.139	*0.054*	*0.139*	*0.054*
Exporter	0.548***	0.205***	0.541***	0.204***
	0.073	*0.026*	*0.074*	*0.026*
Finance_obs	-0.153***	-0.105***	-0.152***	-0.105***
	0.053	*0.024*	*0.053*	*0.024*
Infra_obs	0.055	-0.013	0.056	-0.013
	0.051	*0.022*	*0.051*	*0.022*
Regu_obs	0.045	0.084***	0.044	0.084***
	0.056	*0.023*	*0.056*	*0.023*
MAKE	0.015	0.160***	-0.074	0.207***
	0.057	*0.024*	*0.082*	*0.045*
BUY	0.183***	0.041*	0.133**	0.057**
	0.051	*0.023*	*0.061*	*0.027*
MAKE&BUY			0.156	-0.064
			0.104	*0.051*
Size_medium	0.364***	0.225***	0.369***	0.224***
	0.077	*0.034*	*0.077*	*0.034*
Size_large	0.510***	0.318***	0.515***	0.319***
	0.158	*0.058*	*0.158*	*0.058*
Constant	0.494***	0.620***	0.512***	0.616***
	0.177	*0.075*	*0.178*	*0.075*
Number of obs.	1705	7381	1705	7381
Adj_R2	0.379	0.5434	0.3794	0.5434

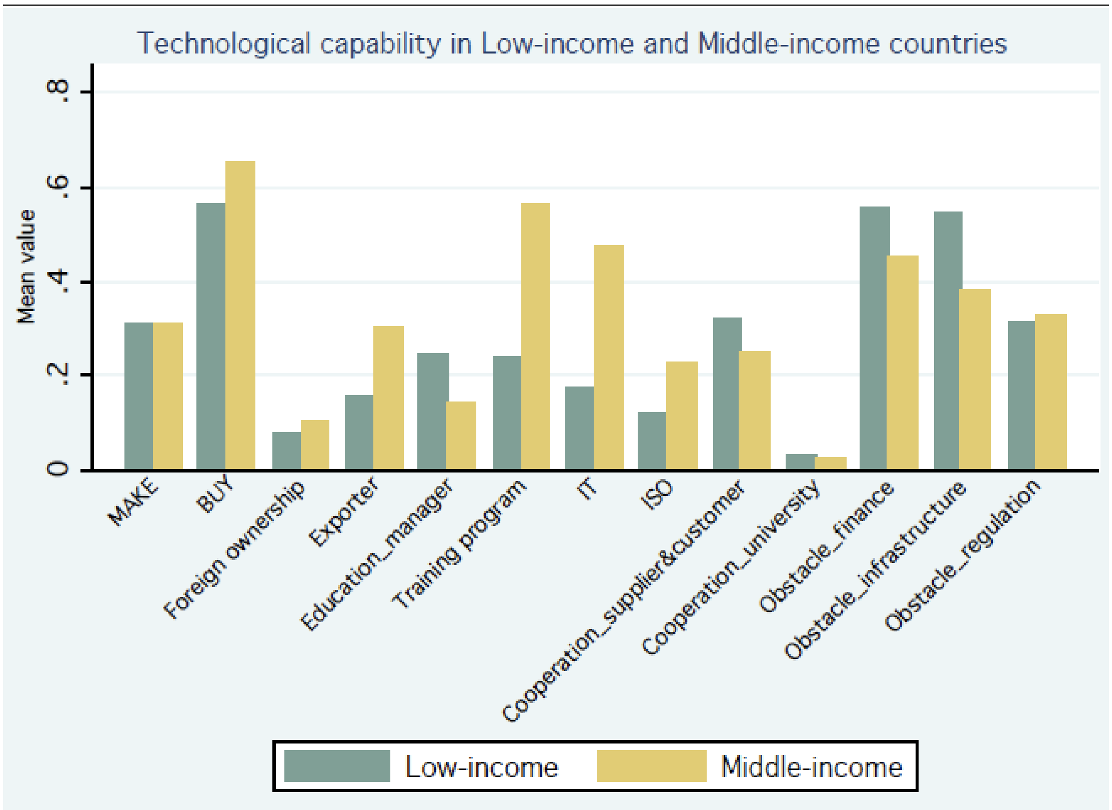
Note: nonmakebuy is the base category. Industry, country dummies are included.
*** Significant level 1%, ** at 5%, * at 10%.

Table 6 Miravete and Pernías approach. Maximum simulated likelihood estimation results

	Bivariate probit		Miravete and Pernías (MP) approach	
	Low-income countries	Middle-income countries	Low-income countries	Middle-income countries
BUY				
Foreign _owner	0.204	-0.111*	0.204	-0.087
	0.140	*0.063*	*0.140*	*0.060*
ISO	-0.078	0.063	-0.078	0.047
	0.110	*0.045*	*0.110*	*0.042*
IT	0.137	0.349***	0.137	0.281***
	0.093	*0.034*	*0.093*	*0.039*
Co_supply/client	-0.322***	-0.223***	-0.322***	-0.232***
	0.070	*0.036*	*0.070*	*0.033*
Co_university	-0.261	-0.366***	-0.261	-0.373***
	0.194	*0.101*	*0.194*	*0.094*
Edu_manager	-0.037	0.288***	-0.037	0.285***
	0.067	*0.034*	*0.067*	*0.032*
Size_Medium	0.063	0.245***	0.063	0.208***
	0.072	*0.041*	*0.072*	*0.041*
Size_Large	0.258**	0.324***	0.258***	0.262***
	0.102	*0.048*	*0.102*	*0.049*
Constant	0.100	-0.063	0.100	-0.037
	0.092	*0.060*	*0.092*	*0.058*
MAKE				
Foreign _owner	-0.202	-0.205***	-0.202	-0.201***
	0.147	*0.063*	*0.147*	*0.064*
ISO	0.102	0.058	0.102	0.040
	0.109	*0.044*	*0.109*	*0.045*
IT	0.064	0.513***	0.064	0.452***
	0.095	*0.035*	*0.095*	*0.041*
Co_supply/client	-0.069	0.171***	-0.069	0.193***
	0.073	*0.037*	*0.073*	*0.038*
Co_university	-0.281	0.326***	-0.281	0.383***
	0.222	*0.105*	*0.222*	*0.108*
Training	0.069	0.530***	0.069	0.541***
	0.086	*0.037*	*0.086*	*0.037*
Size_Medium	0.287***	0.243***	0.287***	0.184***
	0.077	*0.048*	*0.077*	*0.052*
Size_Large	0.336***	0.331***	0.336***	0.256***
	0.107	*0.053*	*0.107*	*0.059*
Constant	-0.450***	-1.679***	-0.450***	-1.776***
	0.091	*0.070*	*0.091*	*0.074*
Complementarity			0.000	0.279***
			0.004	*0.084*
Correlation	0.035	0.101***	0.035	-0.198**
	0.043	0.022	*0.043*	*0.089*
Number of obs.	1705	7381	1705	7381
Likelihood ratio	-2069.274	-8311.584	-2069.2744	-8306.2234

Note: Industry dummies dummies are included.
*** Significant level 1%, ** at 5%, * at 10%.

Figure 1 Innovation sourcing strategies, firm specificities and institutional characteristics in low- and middle-income countries



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